A PULSE POSITION MODULATED LASER COMMUNICATIONS SYSTEM

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Monterey, California

THESIS

A PULSE POSITION MODULATED
LASER COMMUNICATIONS SYSTEM

by

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December 1972

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A Pulse Position Modulated

Laser Communications System

by

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ABSTRACT

An optical communications system, suitable for simplex voice transmission is constructed, and demonstrated for straight line-of-sight, and for curved path operation using lenses and fiber optics. The system uses a pulsed gallium arsenide injection laser in the transmitter, operating at repetition frequency eight to fifteen kilohertz, and a p-i-n photodiode in the receiver. Pulse position modulation is used to transfer information as well as to trigger an avalanche transistor switch to drive the laser.

TABLE OF CONTENTS

I. INTRODUCTION - 8

A. BACKGROUND - - - - - - - - - - - - - - - - - - - 8

B. OBJECTIVES - - - - - - - - - - - - - - - - - - -12

II. DETAILED SYSTEM DESCRIPTION- - - - - - - - - - -14

A. TRANSMITTER- - - - - - - - - - - - - - - - - -14

1. Laser Diode- - - - - - - - - - - - - - - - -14

2. Diode Pulser - - - - - - - - - - - - - - - -19

3. Pulse Position Modulation/Pulser Trigger- - - - - - - - - - - - - - - - - -27

4. Constructed Transmitter- - - - - - - - - -30

B. RECEIVER - - - - - - - - - - - - - - - - - - -34

1. Photodiode - - - - - - - - - - - - - - - -34

2. Photoimpedance Convertor/Final Amplifier- - - - - - - - - - - - - - - - -36

3. Constructed Receiver - - - - - - - - - - -38

C. CHANNEL- - - - - - - - - - - - - - - - - - - -39

1. Lens - - - - - - - - - - - - - - - - - - -39

2. Fiber Optic- - - - - - - - - - - - - - - -39

D. COMMUNICATIONS SYSTEM TESTS- - - - - - - - -41

1. Bandwidth- - - - - - - - - - - - - - - - -43

2. Signal to Noise Ratio- - - - - - - - - - -43

3. Transmission Loss- - - - - - - - - - - - -45

4. Harmonic Distortion- - - - - - - - - - - -45

III. CONCLUSIONS- - - - - - - - - - - - - - - - - - -47

BIBLIOGRAPHY -49

INITIAL DISTRIBUTION LIST- - - - - - - - - - - - - - - - - 51

FORM DD 1473 - 52

LIST OF DRAWINGS

1. Laser Communications System- - - - - - - - - - - - - - - 9
2. Transmitter Schematic- - - - - - - - - - - - - - - - - -14
3. Gallium Arsenide Laser - - - - - - - - - - - - - - - - -15
4. Operating Characteristics of LD22 Laser Diode- - - - -17
5. Luminescence Characteristics of Gallium Arsenide - - -18
6. Frequency Distribution of Telephone Voice- - - - - - -20
7. Avalanche Transistor Characteristics - - - - - - - - -21
8. Characteristics of 2N657 Transistor- - - - - - - - - -21
9. Laser Pulse Circuit Diagram- - - - - - - - - - - - - -23
10. Design Mask for Avalanche Circuit- - - - - - - - - - -24
11. Completed Avalanche Circuit- - - - - - - - - - - - - -24
12. Pulser Characteristics - - - - - - - - - - - - - - - -26
13. Pulse Position Modulation/Pulser Trigger Circuit - - 29
14. Single Pulse from PPM Circuit- - - - - - - - - - - - -31
15. Final Pulse from Booster Circuit - - - - - - - - - - -31
16. Design Mask for PPM/Trigger Circuit- - - - - - - - - -32
17. Completed PPM/Trigger Circuit- - - - - - - - - - - - -32
18. Assembled Transmitter- - - - - - - - - - - - - - - - -33
19. Response of a P-I-N Photodiode - - - - - - - - - - - -34
20. P-I-N Photodiode - - - - - - - - - - - - - - - - - - -35
21. Receiver Circuit - - - - - - - - - - - - - - - - - - -37
22. Transmitter and Receiver with Fiber Optic Link - - - 38
23. Fiber Optic Characteristics- - - - - - - - - - - - - -40
24. Single Fiber Optic Strand- - - - - - - - - - - - - - -40
25. System Response to Sinusoid- - - - - - - - - - - - - -42

26. Frequency Response of System- - - - - - - - - - - -44

27. Harmonic Distortion Tests - - - - - - - - - - - - - -46

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I. INTRODUCTION

A. BACKGROUND

The laser is a source of intense, directional, and coherent radiation. At optical wavelengths (10^{13} to 10^{15} HZ), the bandwidth of a single laser beam can carry all the television programs in this country [Ref. 1]. Lasers can have minimum beam divergences on the order of milliradians with virtually no side lobes. This insures directionality, security, and no cross talk or interference from adjacent beams or even from lower frequency carriers. Terminal equipment takes up only small amounts of space making extremely large high gain antennas unnecessary. Power needed for conventional omnidirectional antennas is not needed for channeling the narrow laser beam.

The laser would then seem well suited for communications purposes; however, there are disadvantages that accompany the advantages. Lasers are very inefficient--most having efficiencies of less than one percent for conversion of input power to optical power. For transmission paths through the atmosphere, light is easily scattered by clouds, smog, rain, etc. Transmission by light pipes is often accompanied by attenuation losses [Ref. 2].

Nevertheless, an optical communication system operates in a similar manner to a conventional system, and may be studied in a similar way. Figure 1 shows a generalized optical communications system.

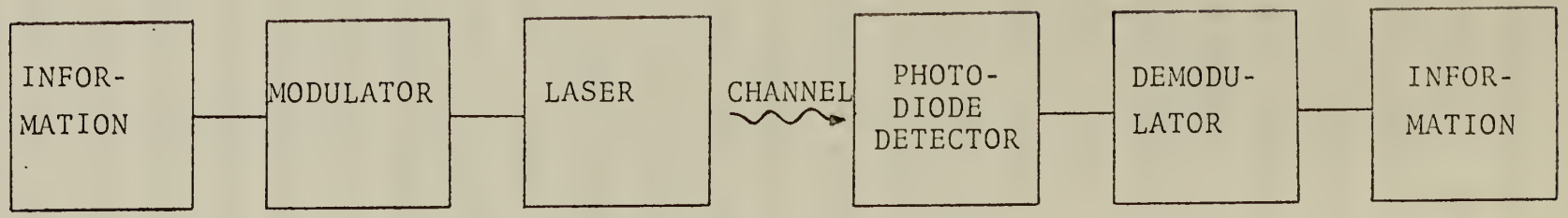


Figure 1: Laser Communications System

Experiments have been conducted with nearly every type of laser for use in optical communications systems. Some of the most interesting tests have been conducted with the gallium arsenide (GaAs) injection laser. Since its discovery in 1962, the GaAs laser has been found to exhibit intensive radiance, and narrow spectral lines, plus it has been found that semiconductor lasers have the highest energy conversion of any laser. This would then seem ideal for use in a communications system. However, because of the small size of the GaAs crystals, these lasers produce small power output. Also, the high current pulses needed to produce laser emissions cannot have repetition frequencies in excess of several kilohertz without requiring cryogenic cooling--a severe limitation in voice communications [Ref. 3].

There are many and varied ways of modulating a laser just as there are for other carrier waves, and the type of laser will limit the type of modulation scheme used. In the case of semiconductor lasers like GaAs, modulation is possible using amplitude, frequency, and pulse modulation; however, experiments have shown that pulse modulation is the most feasible and easiest to implement [Ref. 4].

Perhaps the greatest difficulty encountered in laser communications is the transmission channel. Rain, clouds, smog, and even birds can make atmospheric transmission of a laser ineffective. A better method for some applications is the light pipe. Mirrors and lenses can be placed in a conduit to channel and focus a laser beam. A pipe containing

a gas lens can also be used to channel a laser with little or no attenuation. Still another method of light conduction is the fiber-optic guide. Here the use of lenses and mirrors, and all form of solid reflector is avoided by using a tiny strand of fiberglass whose diameter approaches light wavelengths. The fiber can then function in a similar manner to a microwave waveguide, and transmit in a continuous curved path. There is little or no optical frequency interference between adjacent fibers, and the tiny fiber strands are difficult to tap giving relative transmission security. Commercial grade fibers have the disadvantage of relatively high attenuation. Research continues for the development of a suitable low-loss fiber.

Once a laser signal is transmitted through the channel, detection is a simple matter. Detectors have been developed which display a strong response to incident optical signals, and sufficient instantaneous bandwidth to accommodate the information bandwidth of the incoming signals. They also contribute very little noise to the system [Ref. 5]. Incident light on the photodiode causes a weak photocurrent to flow which can be amplified and demodulated to reproduce impressed information. The p-i-n diode is especially responsive to near infrared radiation making it well suited for use in GaAs laser systems.

Commercial laser communications systems began to appear on the open market around 1970. Two such systems of particular interest were developed by Santa Barbara Research

Corporation [Ref. 6] and by Holobeam, Inc. [Ref. 7]. Both systems make use of the laser properties of GaAs in frequency-modulated semi-secure, directional, short-range walkie-talkies. A third system presently under development at the Navy Electronics Laboratory makes use of the light emitting diode properties of GaAs in a pulse-position modulated telephone circuit. The much higher pulse rates (MHz) possible with LED's lead to better voice transmission and even to multiplexing [Ref. 8].

B. OBJECTIVES

The primary objective of this work was to design, build, and test an optical communications system suitable for simplex voice transmission using a pulsed GaAs laser diode in the transmitter and a photodiode in the receiver. An operational bandwidth of two kilohertz was required to properly represent an intelligible voice signal. The system was to have the versatility of straight line-of-sight communication using lenses as well as non line-of-sight communications using fiber optics. There were no requirements as to power output--only that the system be demonstrated effectively in both above modes. The system was to be used as a laboratory demonstration model of a semiconductor laser communications system with due regard to ease of dismantling and access to various test points.

A secondary objective was compactness in size with the possibility of use as portable equipment. Such a system

might possibly be of interest to the Navy for short-range external or even internal communications aboard ship.

II. DETAILED SYSTEM DESCRIPTION

A. TRANSMITTER

The transmitter consists of three basic parts: the laser diode, the diode pulser circuit, and the pulse position modulation/pulser trigger circuit; see Fig. 2.

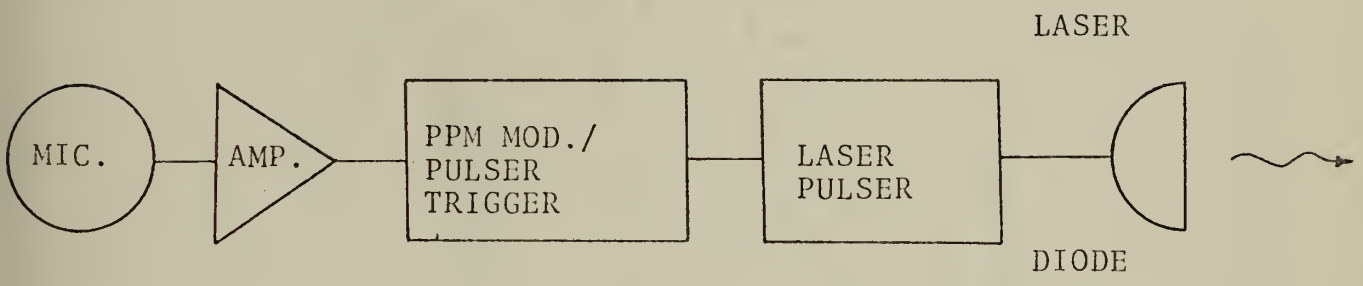


Figure 2: Transmitter Schematic

1. Laser Diode

The source of laser light for the carrier beam is a heterostructure gallium arsenide injection laser diode consisting of n-type GaAs, p-type GaAs, and p-type GaAlAs. See Fig. 3 [Ref. 9].

The passage of current through any semiconductor is caused by the motion of holes and electrons placed in the material by doping. In GaAs crystals, tellurium is used to produce electrons in the n-type material, and zinc is used to produce holes in the p-type material [Ref. 10]. Along the p-n junction in any semiconductor, the holes and electrons recombine to produce radiation of a specific

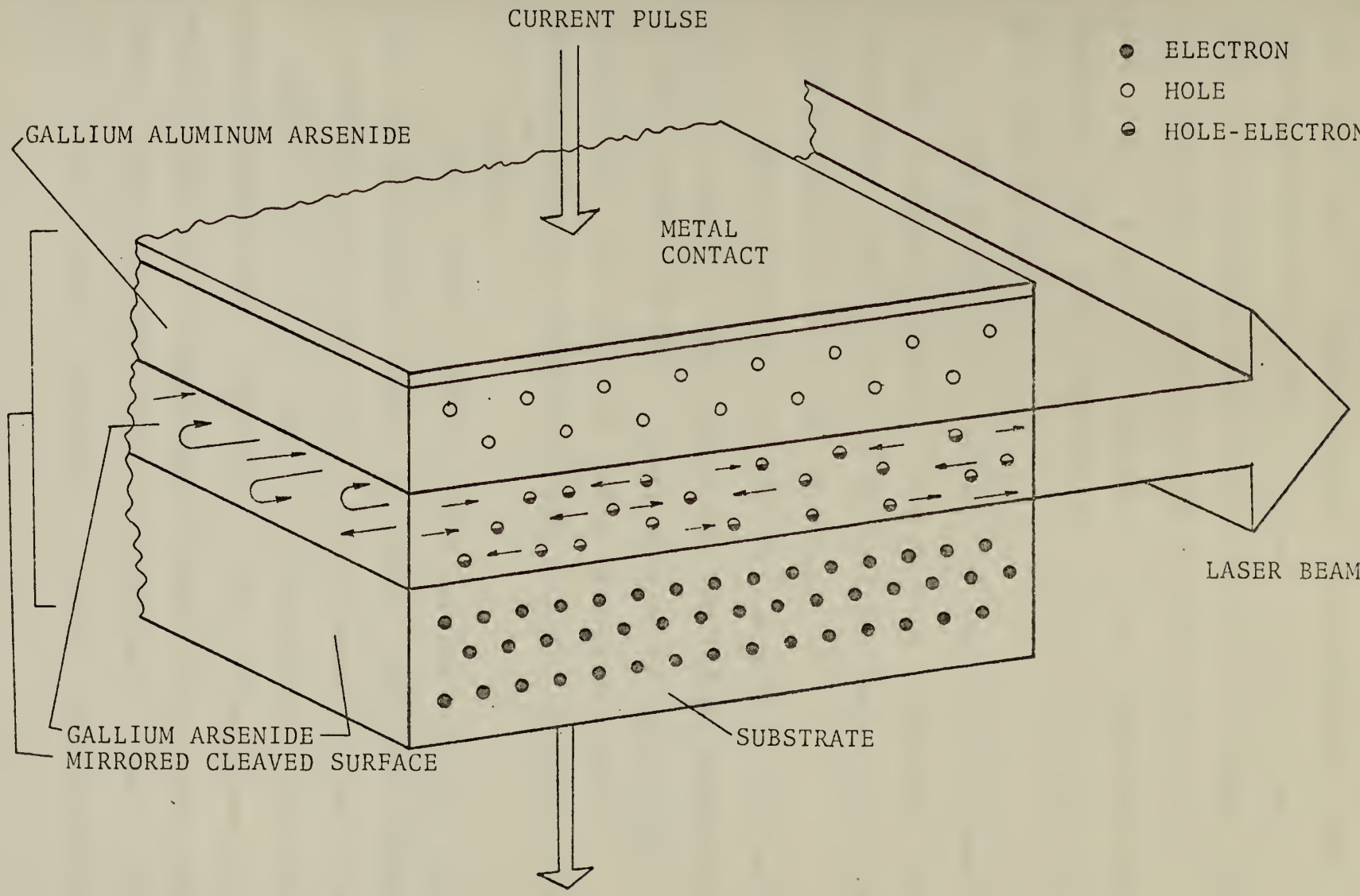


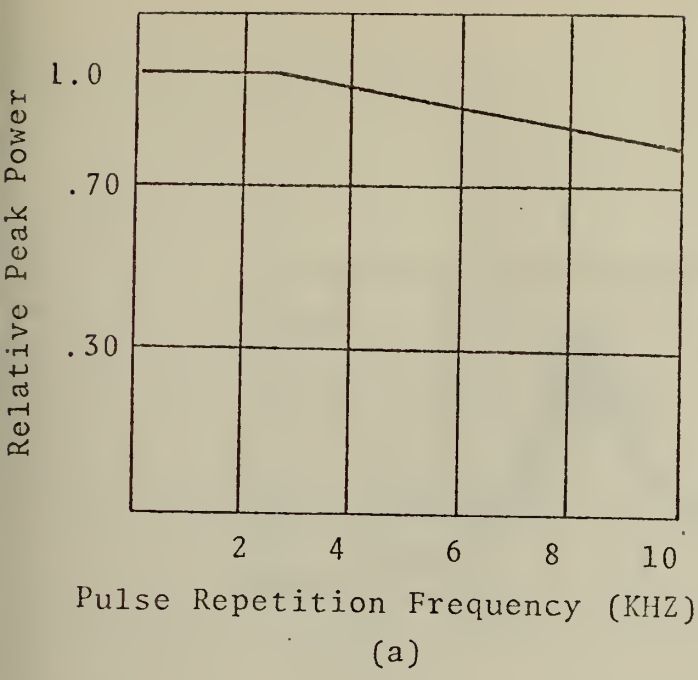
Figure 3: Gallium Arsenide Laser

wavelength depending on the material [Ref. 11]. In GaAs, this radiation is centered around 9050 Angstroms. The interface of the two p-type materials produces a hetero-junction--the junction of two crystals with different lattice structures and different energy levels [Ref. 12]. This acts as a barrier to contain the hole-electron recombination within the center cavity, thereby increasing the device efficiency.

The directionality typical of lasers is achieved in GaAs by proper cleavage of the crystal. This will in effect produce the needed end mirrors to channel the stimulated emissions in the right direction.

Three separate laser diodes were used in this work during testing and experimentation--the TA7606 manufactured by RCA, and the LD22 and 23 manufactured by Laser Diode Laboratories. The LD22 was chosen because of the low threshold current required to make it lase. Figure 4 shows LD22 specifications.

Even with the low threshold current required, the diode did not operate exactly as hoped. The laser threshold is achieved in GaAs only when a strong enough current pulse is applied. Up to that point, the diode shows a much wider spectral luminescence (LED mode). The problem encountered with the LD22 was a random jump between LED and laser modes. Figure 5 shows the difference. The problem, caused by the pulser circuit which is covered in the next section, did not



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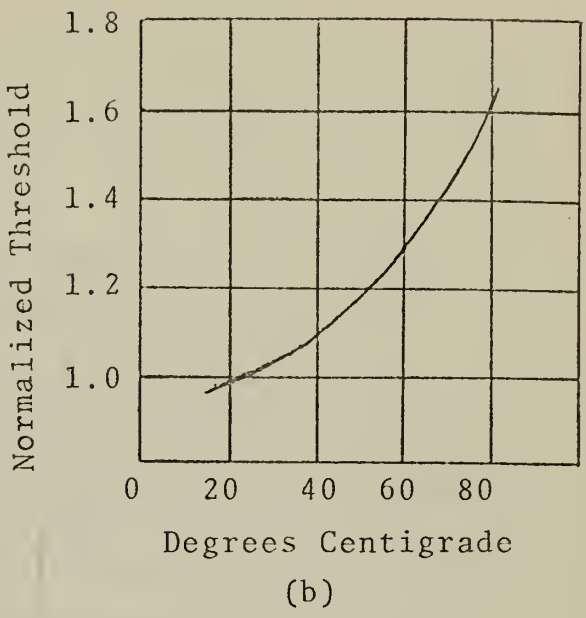

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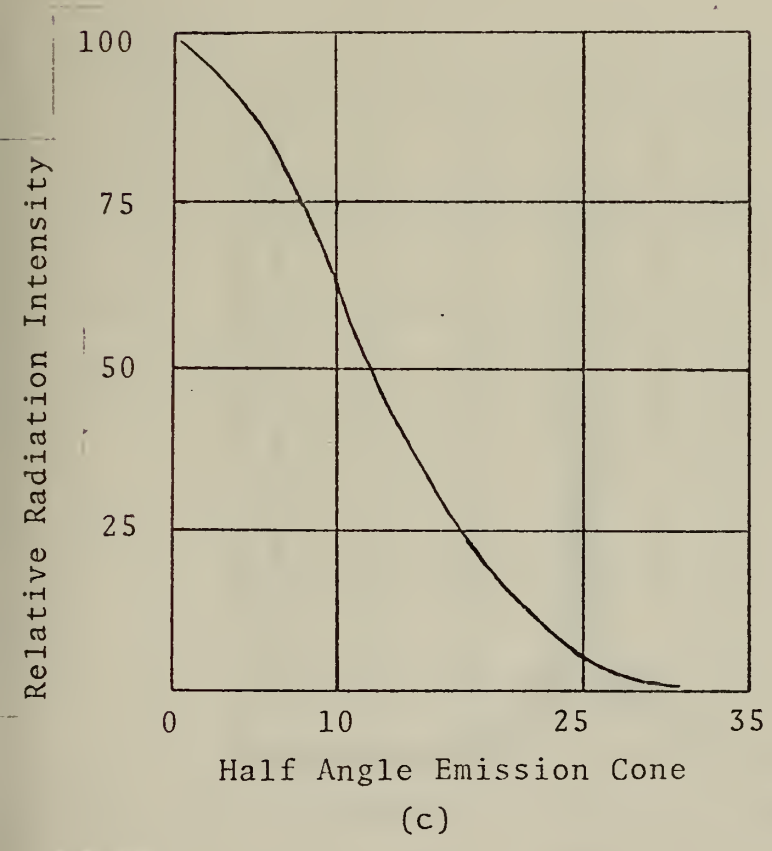

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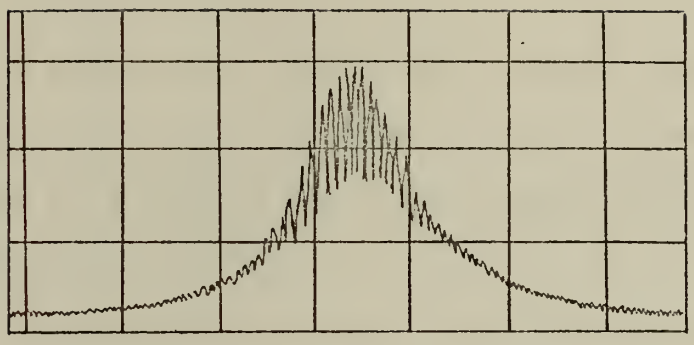
Figure 4: Operating Characteristics of LD22 (a) Relative Peak Power vs. prf (b) Threshold Current vs. Temperature (c) Angular Dependence on relative radiant intensity



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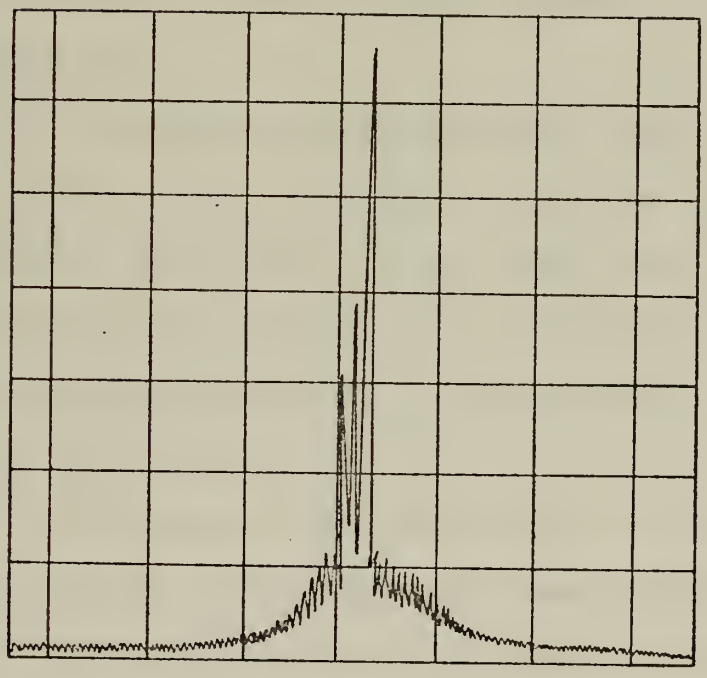
(a)



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(b)

Figure 5: Luminescence Characteristics of GaAs (a) LED Mode (b) Laser Mode

affect system performance since the properties of the system are independent of whether the light was coherent or incoherent.

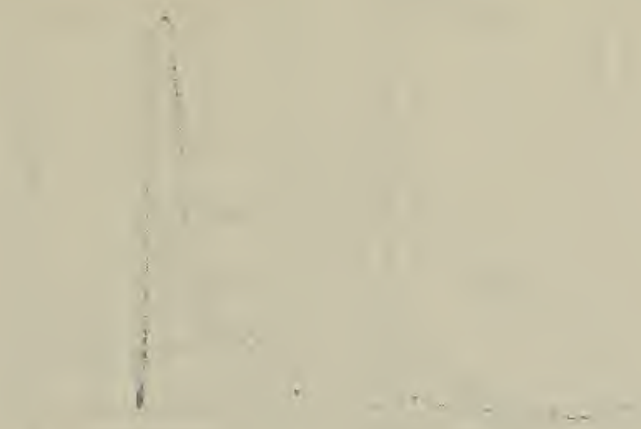
2. Diode Pulser

A pulser was needed which would drive the laser diode strongly enough to make it lase properly, and at the same time be suitable for a pulse-position-modulation communications circuit.

The commercial pulser (LP23 manufactured by Laser Diode Laboratories) was available in the lab. It was compatible with a PPM scheme for external triggering. The LP23 produced one microsecond, 50 amp current pulses with pulse repetition frequency of 1 KHZ. It was thought at first that this prf might be suitable for voice transmission. As seen in Fig. 6, most of the telephone voice is centered around 500 HZ.

A 1 KHZ system would severely limit the fidelity of a voice, but it was felt that it could do the job. Experimenting with this setup, it was found that voice transmission could be achieved; however, it was difficult to filter out the very bothersome hum of a 1 KHZ trigger signal, and still keep any intelligence.

To circumvent this difficulty, a trigger circuit capable of peak current up to 20 amps operating at prf of 10 to 15 KHZ was developed to operate at room temperature [Ref. 14]. By using a capacitance storage circuit along with



C. CHANNEL

Two methods were used to channel the pulse from transmitter to receiver: a lens collimator for line-of-sight transmission, and a fiber optic guide for non line-of-sight transmission.

1. Lens

Very little emphasis was placed on line-of-sight transmission, and setting up an elaborate collimator was avoided. The actual collimator used was an eyepiece from a microscope placed on a six-inch tube to correctly position the lens. The tube was attached to the transmitter directly in front of the diode. A great deal of light energy was lost in the tube before collimation. Even so, the lens increased the visual communications distances from 15 to 30 feet. A more elaborate system would have bettered performance.

Although the p-i-n diode used is most sensitive to infrared wavelengths, it does pick up many spurious unwanted transmissions, degrading receiver performance. Placing an infrared filter in front of the receiver cuts out much of the noise. Some light sources (e.g., the sun, and neon lights) are also infrared sources and may only be partially filtered out.

2. Fiber Optic

A far more interesting channel is the fiber optic. For this work, a ten-foot strand of Corning No. 5011 commercial grade fiber was used. Figure 23 shows the

specifications, and Fig. 24 is a drawing of a single fiber in the bundle.

Type	Corning No. 5011
# of Fibers/Bundle	400
Numerical Aperture	.63
n of Core	1.4
n of Cladding	1.63
Acceptance Angle	80 degrees
Core Diameter	50 microns
Loss	1 db/meter

Figure 23: Fiber Optic Characteristics

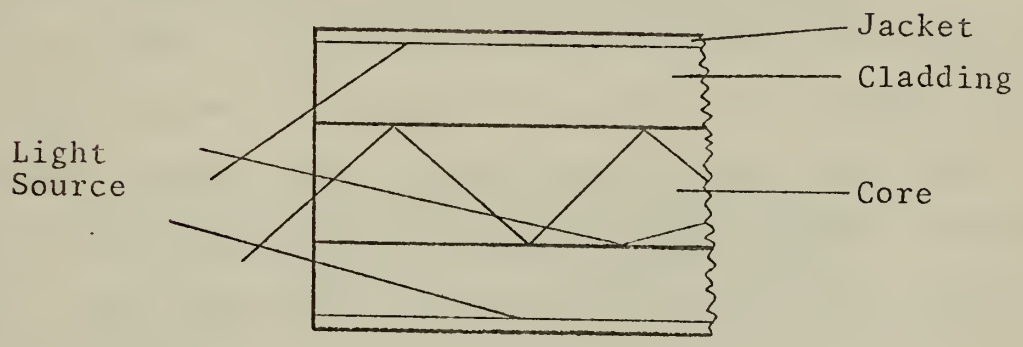


Figure 24: Single Fiber Optic Strand
(after [17])

A single fiber optic consists of a fiberglass strand (core) surrounded by another fiberglass strand (cladding) with a higher index of refraction. Light enters the polished end of the core at less than the critical angle for refraction, and is reflected back and forth from wall to wall as it travels along. As the core diameter reaches light wavelengths, the fiber acts similarly to a microwave waveguide.

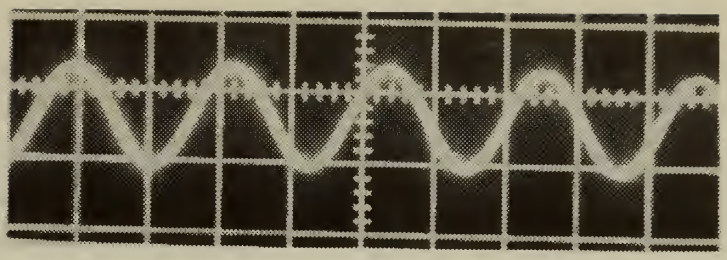
The end of the 400 bundle fiber used for this work was crimped, cut, and polished to allow all light to pass easily. A connection receptable was placed on both transmitter and receiver to allow the fibers to be merely plugged in for a flush connection to the laser and p-i-n diode; Fig. 22.

The fiber optic mode was by far the best means of operation. The acceptance angle of the fiber allowed almost all of the pulsed light to be collected and transmitted to the p-i-n diode. For pulsed operation, losses were negligible. Pulse position modulation does not rely on the height of individual pulses--only the position in time. The high sensitivity of the p-i-n diode, especially to near infrared signals, made operation of the system feasible for even the weakest of pulses.

D. COMMUNICATIONS SYSTEM TESTS

A communications system may be tested by checking system bandwidth, signal to noise ratio, transmission loss, and harmonic distoriton. The most important test, although it is not technical is whether or not it works. For communications purposes, this system was to be able to pass an intelligible voice signal of up to two kilohertz.

Sinusoidal inputs from 50 to 7000 hertz and were injected into the system. Figure 25 shows the input signal, and the recovered output signals at 100, 1000, and 5000 hertz. The carrier prf was varied from 10 to 15 KHZ with almost no



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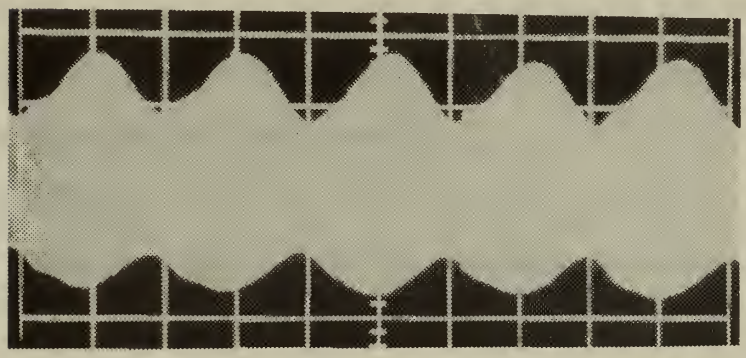

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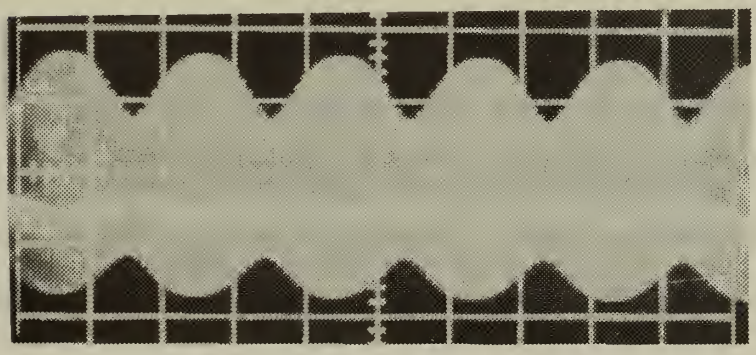

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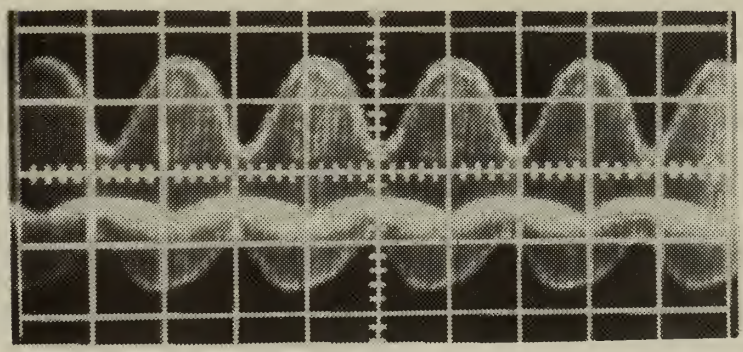

(d)

Figure 25: System Response to Sinusoid (a) Input Signal
(b) Output for 100 modulation, 5 msec/cm
(c) Output for 1 KHZ modulation, .5 msec/cm
(d) Output for 5 KHZ modulation, scale .1 msec/cm Vertical Scale 100 mv/cm

change in signal output. Note that the output contains the input modulation envelope plus the carrier signal. Filtering out the carrier could easily be accomplished by use of an envelope detector; however, it was felt that this was not necessary. The carrier was of too high frequency to be heard by the normal human ear. Only the modulating envelope at the output was heard.

1. Bandwidth

In calculating system bandwidth, it was assumed that each pulse was rectangular, and of pulse width five microseconds, operating at prf of 10 KHZ. The maximum position deviation a single pulse can take with no overlap is the distance between individual pulses less the pulse width of each pulse. For this calculation, that distance was 90 microseconds. The reciprocal of twice that number is a rough estimate of system bandwidth--approximately 5.5 KHZ. This was increased or decreased by the prf control on the transmitter. Figure 26 is a plot of frequency response of the system.

2. Signal-to-Noise Ratio

Signal-to-noise ratio for this system was calculated by measuring the mean output noise power in the presence of a modulating signal, and then measuring the output noise power under noise-free conditions for a sinusoidal input of maximum amplitude. The ratio of these two quantities is the signal-to-noise ratio [Ref. 18].

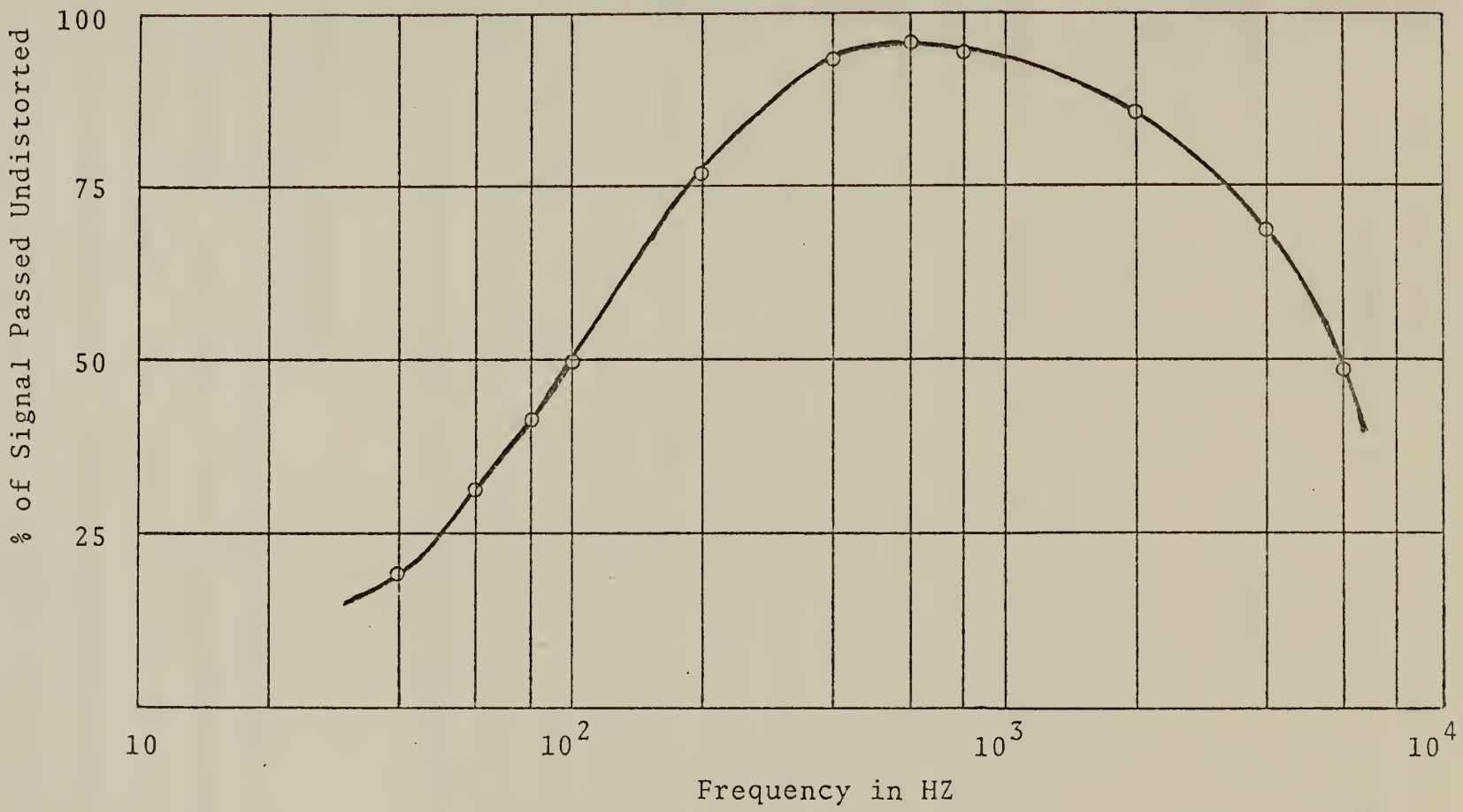

Figure 26: Frequency Response of System

With the fiber connected, a maximum noise level of 15 millivolts and a maximum signal of 300 millivolts with sinusoidal signal was observed. This yielded an rms signal-to-noise ratio of approximately 20:1. Without the fiber optic, the beam dissipated rapidly, and the system yielded a signal-to-noise ratio of up to 5:1, depending on distance between transmitter and receiver.

3. Transmission Loss

The fiber optic loss is rated at 1 db/meter. A test was conducted to determine what length of fiber could be used and still pass information. The fiber was disconnected from the receiver end and moved outward until the photodiode could no longer distinguish signal from noise. At approximately 6 cm distance, the ratio of photocurrent dropped by a ratio of 20:1 or 26 db. At 1 db/meter loss, this would indicate another 26 meters of fiber could be used in the system. This is believed to be a very conservative estimate. For the three meters of fiber actually used, there was no appreciable loss of transmission. It is believed at least 30 to 35 more meters of fiber could be used effectively in the system.

4. Harmonic Distortion

A wave analyzer was used to determine signal content of the fundamental, and second, third, and fourth harmonic of a 1 KHZ input signal. The test was conducted with the system at peak operation with the best possible output. Figure 27 shows the test results. Although the signal

content was 36% at the second harmonic, no distortion was discernable by listening.

Harmonic	Frequency (KHZ)	Signal Content (%)
Fundamental	1	100
Second	2	36
Third	3	7
Fourth	4	Less than 1

Figure 27: Harmonic Distortion Tests

III. CONCLUSIONS

The gallium arsenide injection laser can be used effectively for voice and other low data rate transmissions. Since the diode must be pulsed to operate, a pulse modulation scheme, and especially pulse position modulation is very easy to implement using integrated circuits. Compactness of size and portability may also be maintained.

The bandwidth objective of two kilohertz to pass a voice signal was easily met. With observable bandwidths of up to six kilohertz, future work could be directed toward suitable multiplex systems.

In a pulse-position-modulated optical system, beam coherence is not necessary. The system worked equally well in both LED and LASER modes. The laser puts out a sharper, more powerful pulse, and may increase the transmission distance at the expense of relatively slow pulse repetition frequency, higher power requirements, and overheating for an avalanche system. The LED mode can carry the same amount of information, requires less power to operate, and may be pulsed at much higher rates. The LED system is more efficient.

Although infrared wavelengths make gallium arsenide emissions relatively secure, collimation is difficult for use in line of sight work. With fiber optics, collimation is not necessary. As technology continues in the development of a low-loss fiber, longer distances will become

possible in addition to the numerous advantages of using fiber guides and light for communications.

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13. ABSTRACT

An optical communications system, suitable for simplex voice transmission is constructed, and demonstrated for straight line-of-sight, and for curved path operation using lenses and fiber optics. The system uses a pulsed gallium arsenide injection laser in the transmitter, operating at repetition frequency eight to fifteen kilohertz, and a p-i-n photodiode in the receiver. Pulse position modulation is used to transfer information as well as to trigger an avalanche transistor switch to drive the laser.

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